

THE WEATHER AND CIRCULATION OF SEPTEMBER 1960*

Including a Discussion of Tropical Storm Activity

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1. WEATHER HIGHLIGHTS

September 1960 will be remembered by residents of the Atlantic Seaboard, from Florida to Maine, as the month and year of hurricane Donna. This severe tropical storm dominated weather headlines from its detection in the tropical Atlantic on September 2 until it became extratropical in the Maritime Provinces of Canada on September 13. Preliminary estimates of total damage mark Donna as the most destructive storm ever to strike the United States mainland. The number of fatalities and injuries from Donna were slight in comparison with those sustained from other, lesser storms in the past, and this fortunate outcome can be attributed in major part to widespread and prompt dissemination of accurate and timely warnings.

The sudden development of hurricane Ethel in the central Gulf of Mexico on the 14th was cause for considerable concern to residents of Gulf coastal sections, especially those along the southwestern coast of Florida who had just endured the fury of Donna. The intensity of this new tropical threat fortunately decreased quite rapidly before it reached the coast and moved inland into southern Mississippi on the 15th.

September weather was also highlighted by extreme variability, specifically in respect to the temperature regimes exhibited over the country during the course of the month, as periods of marked cooling alternated with periods of summer-like warmth in many sections. In spite of this variability, temperatures for the month as a whole averaged near to above normal over practically the entire country.

The sharp contrast between record precipitation in the extreme Southeast and Northeast and near to record dryness in some interior and far western areas was an additional highlight of September weather in the United States.

2. MONTHLY MEAN CIRCULATION AND WEATHER

Strong polar blocking, which had dominated the circu-

lation of August [1], receded southeastward during September to a center north of Scandinavia, where 700-mb. heights were 300 ft. above normal (fig. 1). Along with this development, a gradual contraction of the circumpolar vortex took place during the month. This circulation upheaval is indicated by the changes in monthly mean 700-mb. height departures from normal from August to September (fig. 2). Note the significant height falls over the polar regions and the positive changes over the major portions of the United States, Canada, and middle latitudes of the Atlantic. The resulting mean circulation for September was predominantly one of high index from the coast of Asia eastward to the British Isles (fig. 1). Planetary waves were of small amplitude, and the axis of mean 700-mb. zonal wind speed maxima was displaced a substantial distance north of normal over North America (fig. 3). Broad cyclonic curvature characterized the central Pacific trough and its downstream counterpart over the extreme eastern United States. The wavelength between these two systems was long by summertime standards and appears to have been sustained by the stronger than normal westerly circulation. The trough normally active along the west coast of the United States was extremely weak, and positive height departures from normal dominated practically the entire region from the northwestern United States eastward to the central Atlantic.

The simple temperature and fairly well-defined precipitation patterns for the month of September (fig. 4) can be related quite well to the monthly mean 700-mb. height and anomaly patterns (fig. 1), despite the changes in these patterns which took place during the month (section 3). Temperatures averaged above normal in practically all sections of the country (fig. 4A) under predominantly above normal heights. The warm temperatures in the western plateau areas represented a sharp reversal from the cool weather experienced there during August [1]. This warmth was a consequence of upper-level ridge development over the Northwest (fig. 2) and frequent anticyclonic passages in the vicinity of the Rockies (see Chart IX of [2]) which kept the region mainly in southerly flow at sea level. It was the warmest September of record at Ely, Nev. and the month was also notably warm in some interior sections of California.

*Articles on the weather and circulation of October, November, and December 1960 will appear in the Review issues for January 1961, February 1961, and March 1961, respectively. This apparent lag is due to the change in monthly designation of the Review beginning with the current issue. The calendar date of publication is not affected.

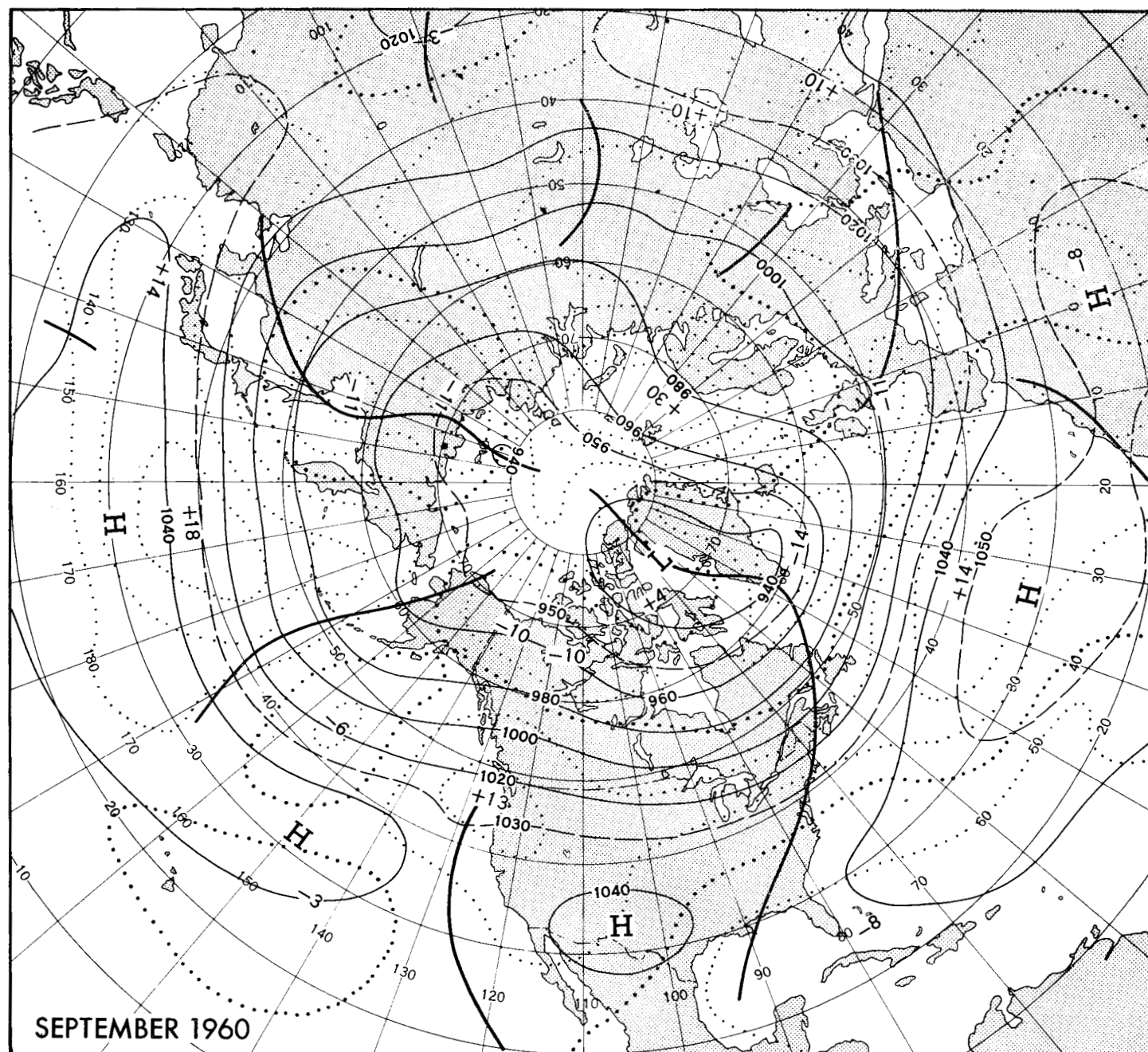


FIGURE 1.—Mean 700-mb. contours (solid) and height departures from normal (dotted) (both in tens of feet) for September 1960. Note contracted nature of circumpolar vortex with strong zonal flow over middle and high latitudes of North America.

Some warming was also experienced in central portions of the country under above normal 700-mb. heights and abundant sunshine, with South Bend, Ind. experiencing the warmest September since 1933. The cooling which occurred in the Middle Atlantic States from August to September can be attributed to increased cyclonic circulation aloft and to stronger onshore flow from the Atlantic. Near to below normal temperatures persisted in most of the extreme Southeast and Gulf coastal sections, where below normal heights and easterly, anomalous flow dom-

inated during the month. This was the coolest September since 1889 at Brownsville, Tex.

Heavy precipitation from Florida northwestward to eastern Tennessee (fig. 4B) resulted mostly from tropical activity moving inland during the month. It was the wettest September and month of record at Miami, Fla., where rainfall totalled 24.4 inches. Well above normal rainfall in the Northeast occurred in conjunction with the passage of Donna early in the month, coupled with scattered showers and frontal rains later in the month.

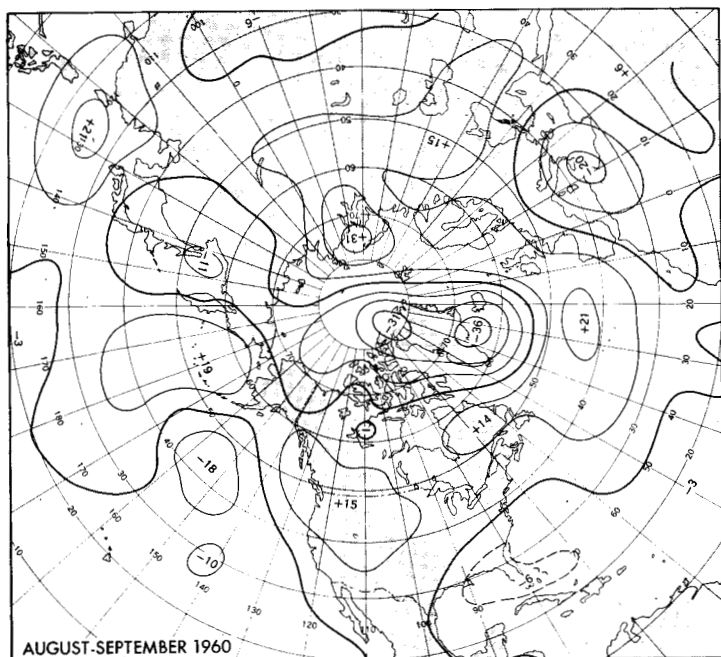


FIGURE 2.—Changes in 700-mb. height departures from normal (tens of feet) from August 1960 to September 1960. Substantial height falls over polar regions are especially noteworthy.

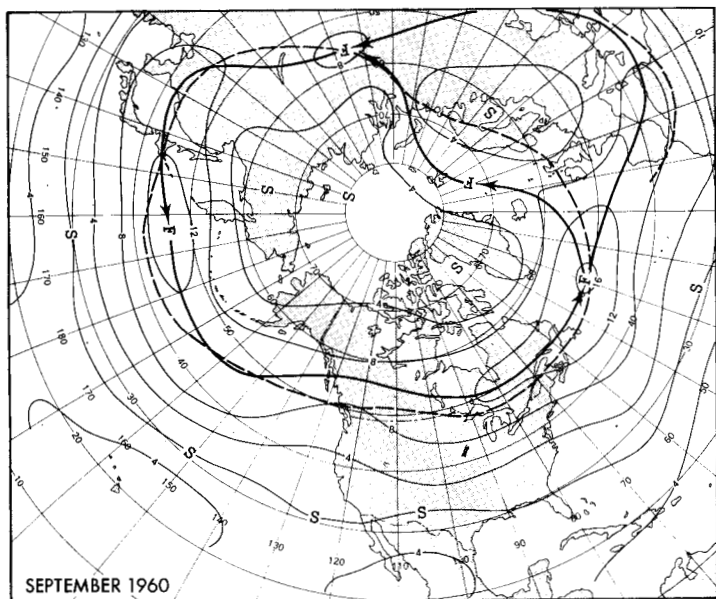


FIGURE 3.—Mean 700-mb. isotachs (in meters per second) for September 1960. Solid arrows indicate axis of wind speed maxima, dashed arrows the normal for the month. The primary axis was north of normal over North America. Subtropical ridge line is denoted by solid line connecting centers of slow wind speed (S).

New record precipitation amounts for September were established at Wilmington, Del., Scranton, Pa., Albany, N.Y., and Concord, N.H. Frequent outbursts of frontally induced convective activity were responsible for twice the normal precipitation in southern Arkansas and substantially above normal rainfall from Wisconsin south-

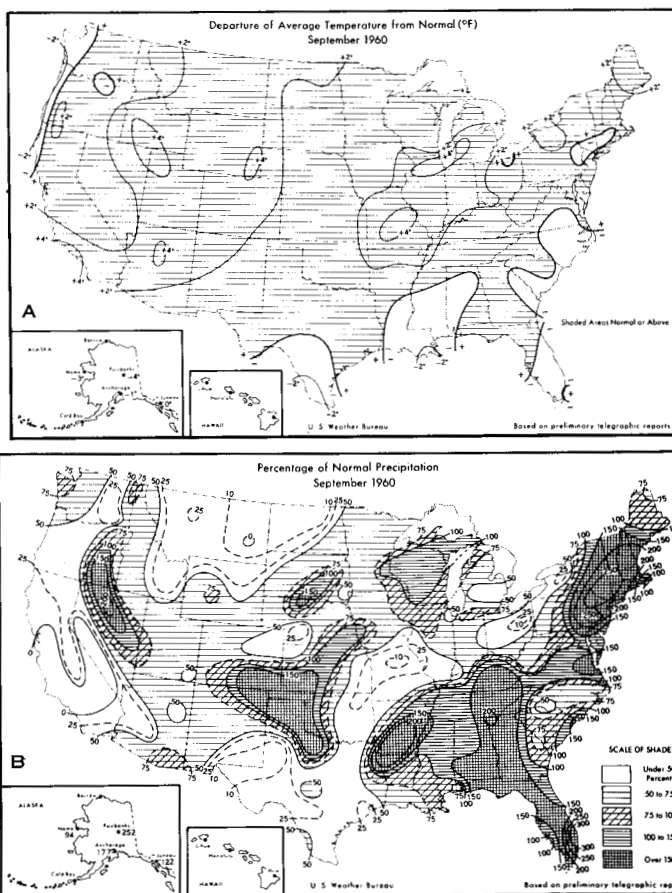


FIGURE 4.—(A) Departure of average surface temperature from normal ($^{\circ}$ F.) for September 1960. The pattern is noteworthy for the predominance of above normal temperatures (shaded) over practically the entire nation. (B) Percentage of normal precipitation for September 1960. (From [11].)

westward to the panhandle areas of Texas and Oklahoma. Predominance of easterly anomalous flow precluded the possibility of any sustained intrusions of moist, Gulf air northward into the mid-sections of the country, resulting in marked dryness from eastern Oklahoma northeastward to western New York. It was the driest September and month of record at Akron, Ohio, and the second driest September of record at Detroit, Mich. and Columbia, Mo. Above normal heights and strong zonal flow collaborated in the production of little to no precipitation over most of North Dakota and Montana, where rainfall deficiencies at Glasgow made this September the second driest of record. Scattered showers, while accounting for the heavy rainfall indicated in north-central Nevada did little to alleviate general drought conditions which have persisted over the State for two years.

That there was a marked predominance of anticyclonic activity in the month's weather, is clearly illustrated by the abundance of migratory anticyclones and the almost complete absence of migratory cyclones in the United States, except along extreme northern border areas (Charts IX and X [2]). This is in good agreement with what one

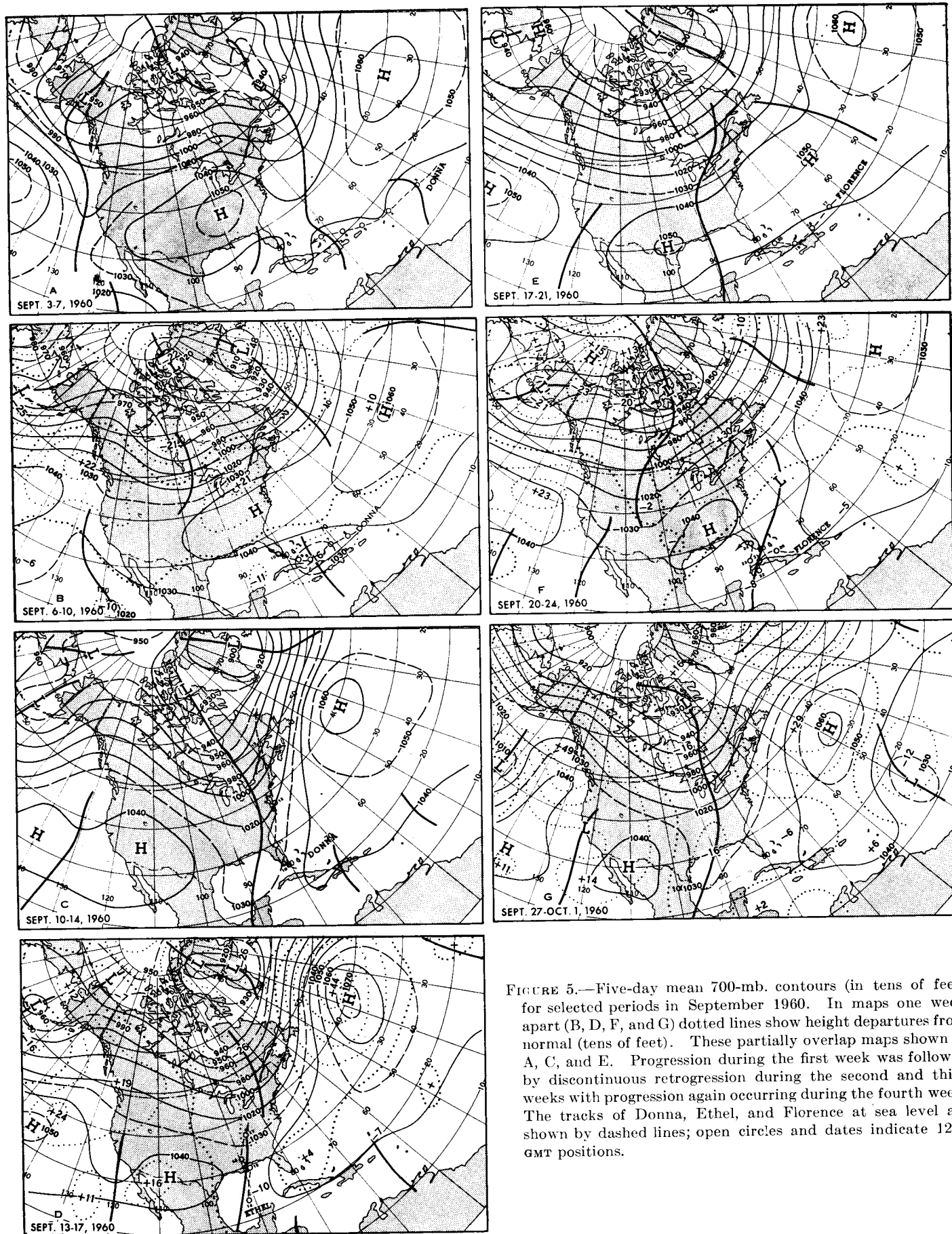


FIGURE 5.—Five-day mean 700-mb. contours (in tens of feet) for selected periods in September 1960. In maps one week apart (B, D, F, and G) dotted lines show height departures from normal (tens of feet). These partially overlap maps shown in A, C, and E. Progression during the first week was followed by discontinuous retrogression during the second and third weeks with progression again occurring during the fourth week. The tracks of Donna, Ethel, and Florence at sea level are shown by dashed lines; open circles and dates indicate 1200 GMT positions.

would expect under a high index regime with the westerlies north of normal and 700-mb. heights above normal over most of the country.

Below normal heights and cyclonic upper flow (fig. 1) resulted in correspondingly below normal temperatures and above normal precipitation over most of Alaska during September. Temperature anomalies of as much as -4°F . and precipitation amounts greater than twice normal were recorded in some interior areas of the State. This was the wettest September since 1925 at Fairbanks, Alaska.

3. TRANSITION WITHIN THE MONTH

The main features of the general circulation over North America underwent three major oscillations during the month of September (fig. 5). There was rapid progression during the early part of the month, followed by apparent retrogression and/or new trough development during mid-month, with gradual progression and amplification again occurring during the latter part of the month. Concomitant with these circulation changes were variations in the temperature and precipitation regimes. These are portrayed on a weekly basis in figures 6 and 7, while the evolution of the circulation is shown by a series of overlapping 5-day mean maps in figure 5.

FIRST WEEK

The circulation over the country during the early part of the week was more typical of mid-summer, with troughs just off the east and west coasts and a strong ridge over the Mississippi Valley (fig. 5A). Unusually hot, humid weather, which began in middle and northern areas east of the Rockies in late August, continued until the 7th or 8th of September. Maximum temperatures exceeding 100°F . occurred at several stations in the Dakotas. A reading of 94°F . at Lansing, Mich. on the 7th established a new record there for so late in the season and some locations in New England experienced their hottest weather of the year.

Rapid progression of the 5-day mean wave train occurred during the latter part of the week, indicating an end to this period of abnormally high temperatures. The trough off the west coast sheared as the northern portion moved eastward to north-central portions of the country, and its downstream counterpart off the east coast advanced to the central Atlantic (fig. 5B). Movement of an extensive, cool air mass from the Pacific Northwest to the Atlantic Seaboard accompanied this circulation change, bringing frosts and subfreezing temperatures to some northern areas and the coolest weather since mid-May to Kansas.

Temperatures for the week (fig. 6A) were well above normal, on the average, over interior California and the Lakes Region under anticyclonic conditions and above normal heights (fig. 5B). Cooling in the Northwest was promoted by northerly anomalous flow over the region. Precipitation in the Midwest and Mississippi Valley occurred in conjunction with a vigorous cold front which traversed these areas during the week (fig. 7A).

The most important weather news of the week and month was hurricane Donna. Its entire track is given in figure 8, and segments corresponding to the period of each 5-day mean map are reproduced in figure 5. Moving on a general west-northwestward track (fig. 5A), this severe storm swept through the northern Antilles late on September 4 and passed just north of Puerto Rico on the 5th, with winds estimated at 140 m.p.h. Taking a more westerly course on the 7th, Donna scoured the northern coast of Cuba during the 9th and then turned northwestward (fig. 5B). It crossed the central Florida Keys early on the 10th, with winds in gusts up to 175 m.p.h. destroying or severely damaging 75 percent of the buildings throughout this section. Turning sharply northward, Donna moved up along the southwestern coast of Florida and passed directly over Ft. Myers at mid-afternoon of the 10th, with wind gusts up to 121 m.p.h. recorded there. Veering northeastward, the storm sped across the main citrus growing areas of the State and moved out over the Atlantic on the morning of the 11th (fig. 5C). Accelerating rapidly Donna continued northeastward and again entered land along the extreme southeastern coast of North Carolina early on the 12th. The storm spread heavy precipitation across Florida and southeastern coastal sections (fig. 7A). More will be said about Donna's development and motion in sections 4 and 5.

SECOND WEEK

Progression of the 5-day mean wave train, which began over North America during the first week, continued into the second week with a full-latitude trough supplanting the strong ridge which had previously dominated the eastern United States (figs. 5C and D.) Below normal temperatures spread over practically the whole eastern half of the nation under below normal 700-mb. heights, with temperature anomalies of -6°F . reported in many areas (fig. 6B). A low of 37°F . at Providence, R.I., on the 17th was the lowest ever recorded there so early in the season. Above normal temperatures were confined to the western and southwestern interior areas under anticyclonic conditions and above-normal 700-mb. heights (fig. 5D). The warmth in the northwestern interior and the cooling in the East represented a marked reversal in temperature regimes from the first to the second week.

Frontal activity and a relatively small storm area produced moderate to heavy precipitation from the east-central Great Plains to the Lakes Region late in the week (fig. 7B).

Hurricane Donna continued to make news headlines as it swept northeastward from the middle-Atlantic coastal sections through eastern New England and the Maritime Provinces of Canada early in the week (fig. 5C). Above-normal tides, heavy rain, and wind gusts up to 130 m.p.h. marked the storm's passage into southern portions of New England during the afternoon of the 12th.

Tropical activity continued during the week with the rapid development of hurricane Ethel in the central Gulf of Mexico on the 14th (fig. 5D). Its position and intensity

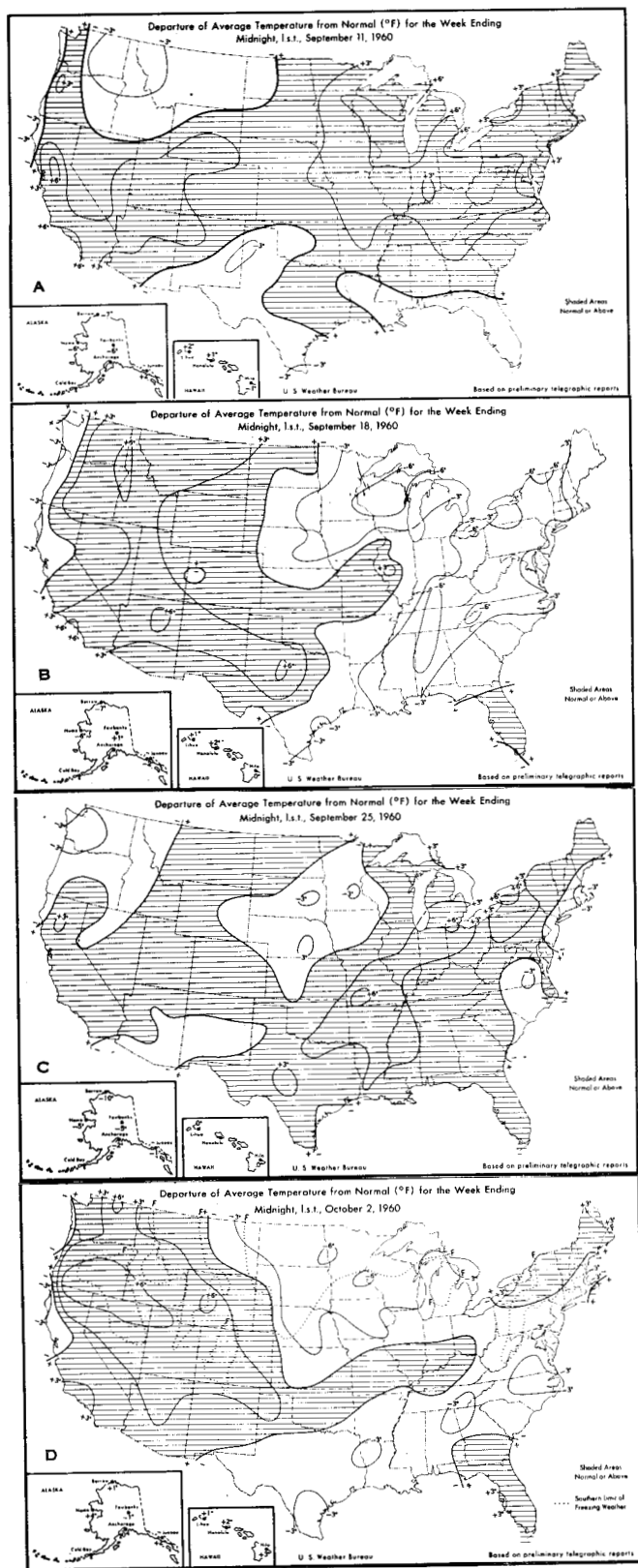


FIGURE 6.—Departure of average surface temperature from normal ($^{\circ}$ F.) for weeks in September 1960 centered on the 5-day mean periods shown in maps B, D, F, and G of figure 5, and ending (A) September 11, (B) September 18, (C) September 25, and (D) October 2. (From [11].) Note the many, and oftentimes marked, reversals in temperature regime which occurred during the month.

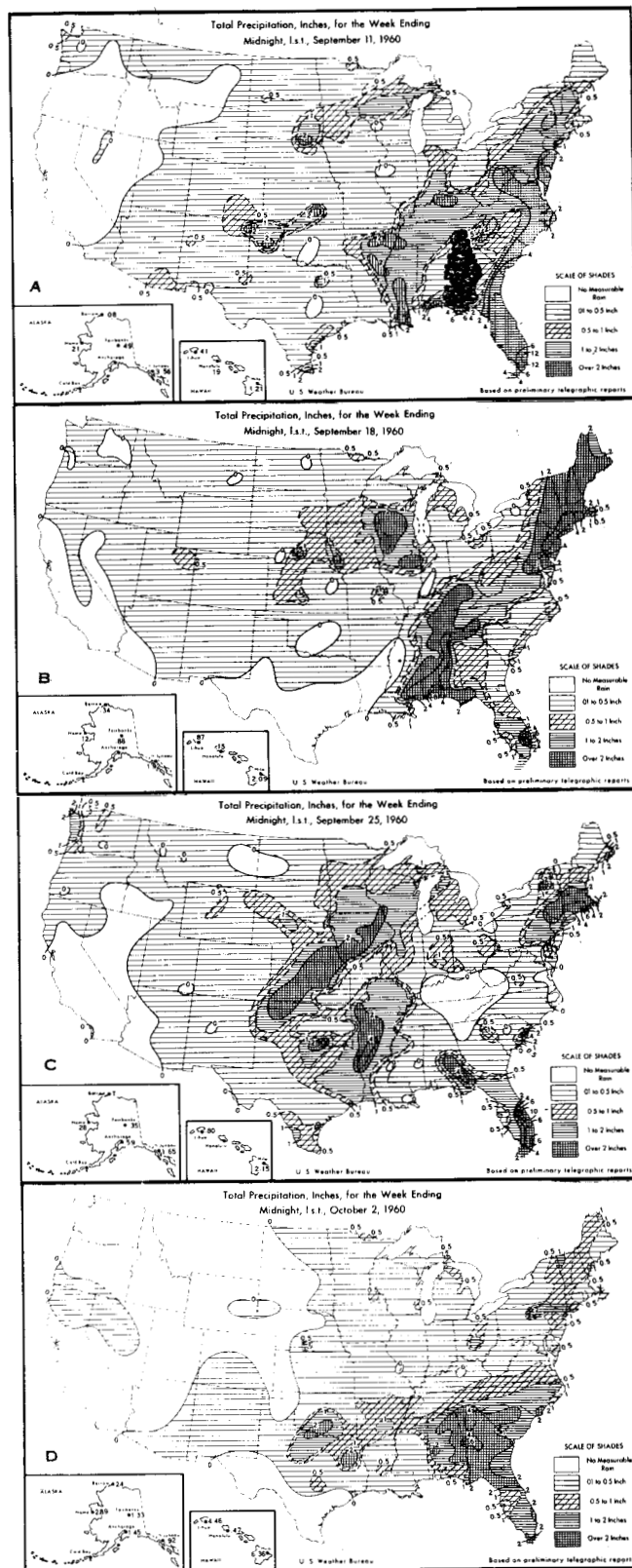


FIGURE 7.—Total precipitation (inches) for the same weeks and from the same source as figure 6. Heavy rains were confined to various sections in the eastern half of the nation during the month.

were established on the basis of reports by the Navy MAMOS (Marine Automatic Meteorological Observation Station), the first detection of a hurricane by this new meteorological instrument. This initially severe storm advanced northward and moved inland with decreasing intensity near Biloxi, Miss. during the afternoon of the 15th, with hurricane force winds observed at but a few scattered stations in the immediate Delta area. The storm continued to fill rapidly as it moved northward during the 16th and 17th, spreading locally heavy rains from Alabama to the central Ohio Valley (fig. 7B). The development and motion of Ethel will be discussed more fully in sections 4 and 5.

The discovery of tropical storm Florence northeast of Puerto Rico early on the 17th (fig. 5E) and its subsequent westward motion along a track closely paralleling that of Donna were additional highlights during the latter part of the week.

THIRD WEEK

The principal circulation features underwent a second major change over the country during the third week, as a trough developed over the Rocky Mountain States and a strong ridge again dominated eastern areas (fig. 5E and F).

Temperatures averaged unseasonably high in the lower Lakes Region and Mississippi Valley (fig. 6C) under anticyclonic conditions and above-normal 700-mb. heights. Large areas east of the Mississippi were as much as 9°–12° F. warmer than the previous week. Cooling in north-central sections and the northwestern interior was associated with more cyclonic flow and near to below normal 700-mb. heights. Rapid drying accompanied the ridging in the East, with little or no precipitation recorded in most areas (fig. 7C). Heavy rain in southern New England occurred in conjunction with cyclonic development just off the coast early in the week. Moderate to heavy rain in the mid-continent was the result of frontal activity during the latter part of the week. Precipitation continued to be very meager in the Far West, where the only significant amounts fell in extreme western Washington as a weak cyclonic center passed across southern Vancouver Island early in the period.

Tropical storm Florence maintained a general westerly course and ceased to pose a major threat to the mainland when it passed inland over northern Cuba late on the 20th and decreased rapidly in intensity (fig. 5E). The much weakened center oscillated sharply southward and then northward across western Cuba during the 22d and 23d (fig. 5F). Remnants of the storm caused heavy rain over southeastern Florida and in areas of extreme southeastern Alabama and northwestern Florida during the last two days of the week.

FOURTH WEEK

The general circulation underwent its third major oscillation over the country during the last week of the month. The trough over the Rocky Mountain States (fig. 5F)

advanced eastward to the Lakes Region and amplified to full-latitude proportions, extending from eastern Hudson Bay southward to the western Gulf of Mexico (fig. 5G). Ridging occurred over the western Plateau, and the low-latitude trough in the Far West receded westward to the northern coast of California.

Average temperatures for the week were well above normal in interior areas of the Far West, with departures ranging up to +6° F. or more (fig. 6D) under anticyclonic conditions and above normal 700-mb. heights. Near to below normal temperatures predominated in the East under correspondingly below normal 700-mb. heights (fig. 5G). Three cold air masses advanced eastward across northern portions of the country during the week (see Chart IX of [2]). Frosts and freezing temperatures from the Dakotas southward to northern Kansas on the last day of the month spread eastward to upstate New York, New England, and scattered sections of Pennsylvania and West Virginia by October 2.

Little or no precipitation fell over the western half of the nation (fig. 7D) under above normal 700-mb. heights and drying, northeasterly anomalous flow (fig. 5G). Heavy rain in the Southern Plains was associated with cold-frontal activity early in the week. General rains in the Southeast and along the Atlantic Seaboard occurred under strong southerly flow of moisture from the Gulf of Mexico, with 3 or 4 days of rather dismal weather highlighting the week's activity in these areas.

4. TROPICAL STORMS RELATED TO THE MONTHLY CIRCULATION

Of the three tropical storms which formed in the Atlantic and Gulf of Mexico during this September, two developed to full hurricane intensity. These figures correspond to mean frequencies of three storms and two hurricanes during the past 73 Septembers, but they are slightly less than the mean September frequencies of the past 10 years.

The mean 700-mb. anomaly pattern for the month (fig. 1) did not exhibit any striking similarity to the overall patterns found by Ballenzweig [3] as favoring development in particular segments of the Atlantic hurricane areas, except for some correspondence to the pattern favoring development in the eastern Atlantic. This is in itself of some interest, considering the diverse areas in which the month's tropical activity originated; Donna off the west coast of Africa, Ethel in the central Gulf of Mexico, and Florence northeast of Puerto Rico (fig. 8). All three storms developed, however, under a circulation regime considered most propitious for hurricanes; i.e., during a time of generally high index with the westerlies somewhat north of normal. This is in good agreement with the proposal by Namias [4] that a northward shift of the westerlies generally is associated with frequent shearing of polar troughs, thus providing a mechanism for maintaining cold air and cyclonic vorticity in the Tropics after transportation from northerly latitudes.

The behavior of the tropical storms (fig. 8) can be

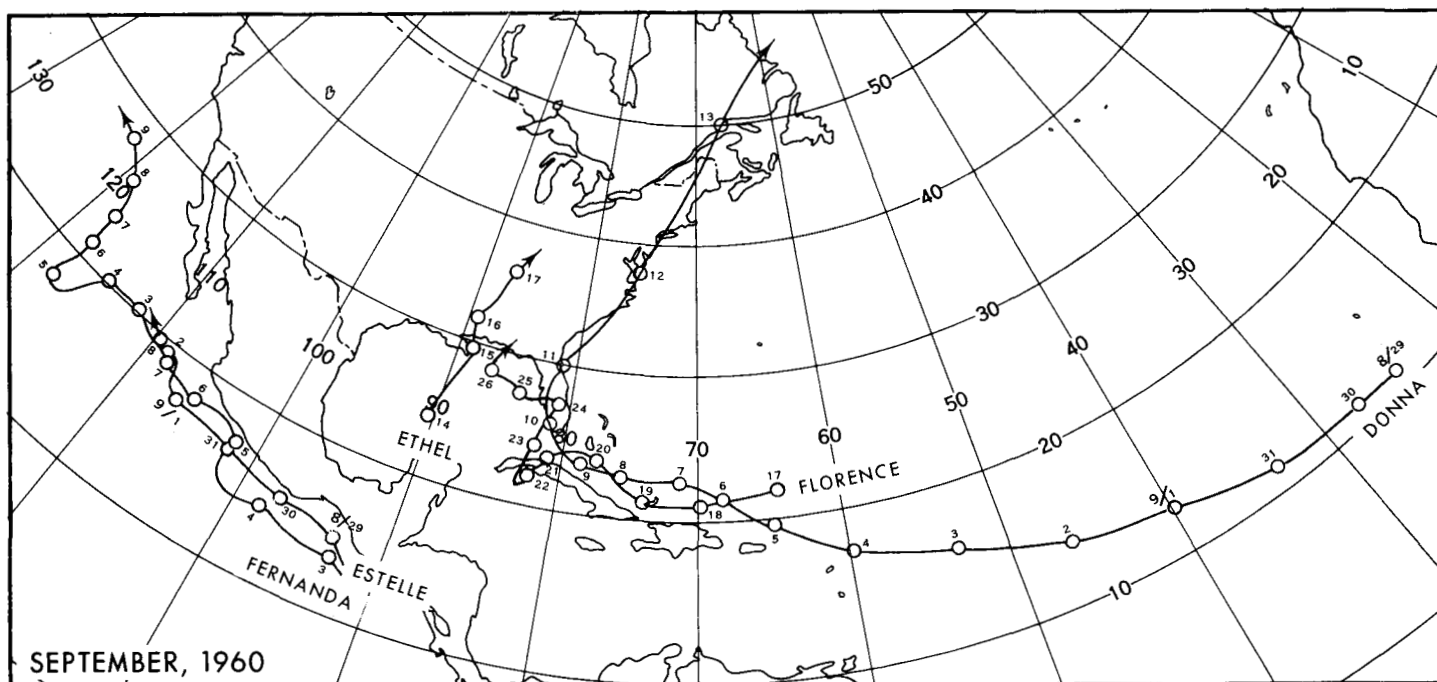


FIGURE 8.—Preliminary tracks of tropical storms during September 1960 in the Atlantic and eastern Pacific Oceans. Open circles and dates indicate 1200 GMT positions.

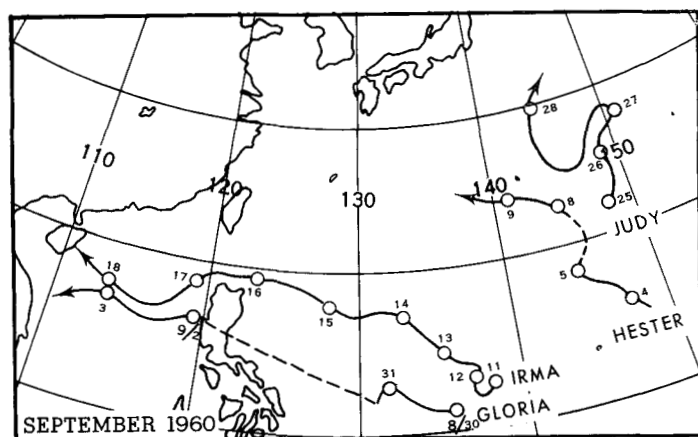


FIGURE 9.—Preliminary tracks of tropical storms during September 1960 in the western Pacific Ocean. Open circles and dates indicate 1200 GMT positions.

700-mb. map (fig. 1) from southern New England southward to Florida and the eastern Gulf Coast States, implying a high degree of vulnerability to tropical activity in these areas.

EASTERN PACIFIC

Of interest this month were two tropical storms in the eastern Pacific (fig. 8), both of which were of hurricane intensity. Estelle was actually a carry-over from the previous month, having formed just south of Guatemala on the 29th of August. The track of Estelle paralleled the mean flow (fig. 1) as the storm moved west-northwestward and then recurved northward and westward and dissipated in the low-latitude mean trough west of Baja California on September 9. Fernanda developed in approximately the same area as Estelle, just south of Guatemala, on the 3d and moved west-northwestward with the mean flow, dissipating west of central Mexico on the 8th.

WESTERN PACIFIC

The most striking aspect of the month's tropical activity in the western Pacific was the complete absence of storms of typhoon intensity. Four storms were in evidence during various periods of the month (fig. 9), none of which developed beyond the tropical storm stage. In fact, two of the storms, Hester and Gloria (a carry-over from August) were so weak and small that their respective circulations apparently were not discernible for days at a time (dashed portions of tracks in fig. 9). This was in marked contrast to the unprecedented typhoon activity which dominated this area during the previous month [1].

A comparison of the mean circulation of August [1] with that of September (fig. 1) suggests that the whole pattern in the western Pacific shifted southward and

interpreted in terms of the monthly mean circulation (fig. 1). Donna's track paralleled very closely the mean contours across the southern Atlantic from western Africa to Florida. After recurvature, Donna moved sharply northward just east of and in the mean trough along the east coast. Hurricane Ethel moved north-northeastward along the mean trough in the central Gulf of Mexico. Similar motion of hurricanes in relation to the mean circulation has been noted by Klein [5] and discussed in many articles of this series. The movement of tropical storm Florence southward across western Cuba does not fit the 30-day mean pattern too well. However, weak remnants of the storm did eventually move northward east of the mean trough in the Southeast. Note also the strong easterly, anomalous flow components on the mean

eastward about 10° of latitude during September. The persistent Low over Formosa in August, which served as a sink for the cyclonic vorticity of the many typhoons, might conceivably have been absorbed northward into the westerlies early in September. This could have contributed to the development of the mean trough along the coast of eastern Siberia. The subtropical ridge was stronger than normal in the west-central Pacific ($+180$ ft., fig. 1) and extended strongly westward south of Japan to eastern China. The marked southeasterly and convergent anomalous flow south of Japan in August (see fig. 1 of [1]) was replaced by a northeasterly and strongly divergent anomalous flow during September.

Tropical storms Gloria and Irma developed some distance east of the Philippines and moved west-northwestward with the mean flow. Both storms eventually dissipated in the same general area of the South China Sea (fig. 9). Hester and Judy were relatively weak and short lived storms which developed southeast of Japan. Both storms moved northwestward and were absorbed into strong cold-frontal systems which had moved southeastward from Japan.

5. TROPICAL STORMS RELATED TO THE 5-DAY MEAN CIRCULATION

The relation of the tropical storms of the Atlantic to the 5-day mean circulation is deserving of special attention, especially since the paths of the storms are often influenced by short-period means.

The exact conditions which led to the inception of Donna off the western coast of Africa during late August can only be surmised due to the paucity of data in this particular segment of the Atlantic. It is quite likely, however, that the initial disturbance was in the form of a severe West African squall line of the type described by Regula [6]. The first advisory on Donna was issued on September 2 with the storm some 700 miles east of the Lesser Antilles and already of full hurricane proportions. Donna moved on a general west-northwestward track with the mean flow, arriving in the extreme eastern Bahamas on the 7th (fig. 5A). Note the slowing down of the storm's forward progress from the 5th to the 7th and the turn to a more northwesterly direction as it approached the mean trough off the east coast. It was unfortunate that the general circulation underwent its first major oscillation of the month at this time when conditions appeared rather propitious for possible northward recurvature of the storm well off the coast. As it was, rapid progression of the 5-day mean waves occurred, with the trough off the coast shearing and moving to the central Atlantic, and the strong High over the Mississippi Valley advancing eastward to the coast and effectively bridging the gap north of the storm (fig. 5B). Donna, accordingly, turned again to a more westerly course, recurving sharply northward across Florida on the 10th and up along the full length of the Atlantic Seaboard in advance of the full-latitude trough which settled in over the East (fig. 5C). A rather intensive report on hurricane

Donna, including a general summary of the storm's track, major features of the storm in seriously affected island and continental areas, plus some comparisons of various forecasting techniques in their application to Donna, is being prepared by Haggard and Cry of the U. S. Weather Bureau*.

Dunn [10] has indicated that trailing, stationary, or fractured portions of old polar troughs may provide the initial concentration of cyclonic vorticity necessary for hurricane formation. This certainly appeared to be the case in regard to the development of hurricane Ethel just east of the trailing, southern portion of the mean polar trough in the central Gulf of Mexico on September 14 (fig. 5D). The storm moved north-northeastward along this trough, entering the coast near Biloxi, Miss. on the 15th. The storm continued northward with rapidly diminishing intensity, eventually dissipating in the Tennessee Valley on the 17th.

Tropical storm Florence developed from an easterly wave which moved through the Lesser Antilles during the 16th. The circulation was first detected northeast of Puerto Rico on the 17th, and the storm moved westward with the mean flow, entering land in northwestern Cuba during the 21st without ever attaining hurricane strength (fig. 5E). Weak remnants of the storm oscillated southward and northward across western Cuba to Florida from the 21st to the 24th near a mean trough in an area of very weak gradient (fig. 5F). This track may have been influenced more by prevailing surface conditions in the area than by mean circulation features.

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*Shorter accounts of the storm's passage through various parts of the United States have been published [7, 8, 9]